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Discounting Collateral: Quants, Derivatives, and the Reconstruction of the ‘Risk-Free Rate’ after the Financial Crisis

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Abstract

Serving as a pledge against a future promise, collateral has traditionally been understood as a 'back office' technicality that reduces the risk of default. Yet in the wake of the 2008 financial crisis and the erosion of faith among market participants in the credit quality of large banks, collateral is playing an increasingly important *epistemic* role within finance, as an anchor that underpins the valuation of a growing number of financial instruments. This paper explores the increasing importance of collateral to the modelling practices used by 'quants' to value 'over-the-counter' interest rate derivatives since the 2008 financial crisis, and how the inclusion of collateral expertise into quants' own modelling practices has affected these markets. This historical episode suggests that while the inclusion of collateral expertise into banks' front office modelling practices has made banks' pricing models less abstract and more aligned to the traditionally overlooked legal practices that underpin derivatives trading, it has also led to an explosion of complexity in the valuation of these instruments that now threatens the future existence of these markets.

Keywords

Collateral, Valuation Practices, Financial Modelling, LIBOR, Interest Rate Derivatives, Financial Crisis

Introduction

The use of collateral is typically understood as a solution to the problem of managing 'credit risk': the risk that a debtor may fail to make good on a promise to its creditor. As such, collateral exchange is often seen as a straightforward practice that underlies the exchange of financial instruments, but is relatively separate from the valuation of those instruments. In traditional neoclassical descriptions of markets, for instance, collateral is absent: instead, all economic agents are assumed to keep their promises (Debreu 1959). Where economists have explicitly theorized collateral, it is often conceived of as a substitute for legal or social penalties that would otherwise be effective in forcing market participants to make good on their commitments (Geanakoplos 1999). Yet as several of the other articles within this issue emphasize, these traditional perspectives fail to fully capture the causes and consequences of the growing use of collateral within the financial markets. Indeed, in the last two decades – and particularly since the 2008 financial crisis – the use of collateral-based techniques of finance has accelerated, a shift that has engendered profound changes in the relationship between the state and financial markets, the operation of central banks, and stability of the financial system (c.f. Gabor 2016; Mehrling 2011; Boy 2015).

The present article contributes to these various perspectives by presenting a micro-level account of the changing role of collateral since the financial crisis within banks that 'make markets' for interest rate derivatives that are traded on an 'over-the-counter' (OTC) basis. Within most banks, the pricing and trading of interest rate derivatives was organizationally and cognitively separated from the management of the collateral backing those derivatives prior to the global financial crisis. Since the downfall of the London Interbank Offered Rate (LIBOR) beginning in 2008, however, this separation has broken down as collateral has taken on an increasingly important *epistemic* role. In addition to reducing credit risk, collateral is now instrumental in allowing banks to come to agreement about the value of interest rate derivatives in a world in which every bank faces different funding costs. No longer a 'black box' to traders and bankers in the front offices of financial institutions, the specific features of the collateral backing interest rate derivatives have come to figure prominently in the valuation of these instruments. The growing epistemic importance of collateral to derivatives valuation has, in turn, had unexpectedly profound effects on the internal organization of banks, as well as the complexity and transparency of banks' valuation practices.

My empirical focus within this paper is on the modelling practices used by derivatives 'quants': the predominantly PhD-trained mathematicians, engineers, and physicists who are employed by dealer banks to build and maintain the models and infrastructures used to value these instruments. Prior to the financial crisis, quants used LIBOR and rates derived from LIBOR to calculate the present value of OTC derivative cashflows due its perceived capacity to represent not only the 'risk-free rate of interest' but also the funding costs of large banks and financial institutions. Following the 2008 crisis and the downfall of LIBOR, quants faced the problem of adapting existing derivatives valuation practices to a world in which banks could no longer borrow and lend money at a unique 'risk-free' interest rate. Over time, the quant community soon came to a consensus that this new economic reality implies that every bank should in turn assign a different monetary value to a derivative when the derivative itself is not backed by collateral. Among quants, the downfall of LIBOR and the divergence of banks' funding costs led to an intellectual crisis as some of the most fundamental assumptions of their models became invalidated. Indeed, in the post-crisis financial markets, even the simplest uncollateralized derivatives sold by different banks became incommensurable goods: a client requesting a valuation for an uncollateralized derivative from a set of dealer banks would be given a range of valuations depending on the financial characteristics of the bank valuing the instrument, a fact that could severely affect the liquidity and transparency of these markets.

Along with complementing existing macro-oriented accounts of the downfall of LIBOR and the rise of collateral-based finance (c.f. Bryan and Rafferty 2016; Gabor 2016), this paper contributes to an ongoing debate over the merits of science-studies-oriented approaches to the study of financial markets. Since its inception in the early 2000s, the social studies of finance has largely focused on developing a sociology of financial markets that emphasizes the material artefacts and processes – such as models, algorithms, and market devices more generally – that constitute and frame markets by providing market participants with shared knowledge of the value of securities. A prominent critique of this approach that has emerged in recent years – made by both Philip Mirowski and Annelise Riles – is that by treating finance as analogous to scientific practice, the SSF has downplayed the importance of politics in the construction of markets (c.f. Mirowski and Nik-Khah 2008; Riles 2010). Moreover, Riles (2010) further argues that by focusing on the 'front office' activities of pricing and market-making and viewing these activities primarily through an epistemic lens, the SSF has inadvertently reproduced rather than challenged financiers' own culturally-situated understanding of financial markets, which tends to downplay the importance of forms of expertise – including what Riles refers to as 'collateral expertise' – that operate on the periphery of the trading floor.

This paper addresses the second of these critiques. I argue that understanding the changing role of collateral within the interest rate derivatives markets since the financial crisis requires that one pay more, rather than less, explicit attention to the interaction between collateral itself and the social and technical processes that allow market participants to reach consensus about the value of interest rate derivatives. Nevertheless, Riles rightly identifies a significant blind spot within existing work in the SSF: With some notable exceptions (c.f. Muniesa 2011; Lepinay 2011), the field has generally steered away from producing empirical work on the 'back office' of financial institutions, and perhaps more importantly, the way in which 'back office' expertise tends to be downplayed and overlooked by front office traders and market makers. Drawing on the STS-oriented literature on infrastructure, this paper argues that this blind-spot can be remedied by paying more explicit attention to processes of infrastructuralization: that is, how practices, devices, and modes of expertise come to be treated as infrastructure by particular actors within finance, and in doing so, become taken-for-granted or even invisible to those actors. This represents a subtle but important change in perspective for the SSF. Rather than seeing infrastructure merely as a collection of technical objects, this perspective draws attention to the *relational* property of infrastructure: Whether a collection of objects counts as infrastructure (and hence becomes backgrounded and taken-for-granted) depends on an actor's relationship with those objects.

In the case of interest rate derivatives, the mathematical practices underlying their valuation and the legal practices underpinning the exchange of collateral evolved independently from one another from the mid-1980s onward, and were largely kept organizationally separate within financial institutions. But even as the infrastructuralization of collateral masked the underlying political dimension of finance, it contributed to the liquidity of markets by reducing the complexity of derivatives valuation. In this sense, the black-boxing of back office knowledge served a productive function for market participants. On the other hand, I show that the infrastructuralization of collateral was a fragile achievement: It depended upon banks being able to lend money to each other at an approximately risk-free interest rate, i.e. LIBOR. When LIBOR ceased to be a credible indicator of banks' true funding costs and bank funding costs themselves diverged, market participants faced the problem of determining a unique market price for interest rate derivatives.

For quants and traders, *collateral itself* offered a potential solution to this problem of incommensurability: because the interest earned on collateralized lending is one of the few funding costs that is still shared by all banks and financial institutions, quants reasoned that market participants should — in principle — still be able to come to a consensus about the value of derivatives that are backed by collateral. However, due to the previously ignored complexity of collateral-related practices, the move to collateral-based valuation engendered as much complexity as it foreclosed: Collateral no longer being a taken-for-granted back office practice, traders and quants began paying more attention to the details of the legal agreements underlying collateral exchange, who then sought to fully value – and even monetize – certain features of these collateral agreements that were previously ignored. This, in turn, has led to an explosion of complexity in the valuation of these derivatives, which now seems to be threatening the future existence of these markets.

This article has eight sections, including this introduction. In the next two sections, I draw upon existing anthropological and STS-inflected work on infrastructure to sketch how the SSF can develop a more thoroughly relational account of financial infrastructure, and then discuss the sources from which the empirical component of this article was developed. Sections three and four respectively examine the infrastructures that make up the focus of this article: the mathematical techniques used to discount the future cashflows of interest rate derivatives, and the techniques that underpin the exchange of collateral backing those derivatives. Sections five through seven examine the impact of the financial crisis on these infrastructures, while section eight concludes.

Collateral, Valuation, and the Social Studies of Finance

With its focus on the connection between the practices of valuation and collateralization, the episode examined in this article contributes to a growing body of work within economic sociology and related fields on the technical practices that underpin real-world economic markets. Since the inception of the 'new' economic sociology in the mid-1980s, a central occupation of the field has been to understand the social structures that constitute market exchange with the aim of creating a more accurate account of markets than that provided by neoclassical economics. In the last fifteen years, the social studies of finance (SSF) has provided a new set of perspectives, largely drawn from the field of science and technology studies (STS), which emphasizes how material devices and calculative practices underpin the social order of markets. In doing so, the SSF has largely viewed the emergence of markets through an epistemic lens: The existence of a market, from this perspective, requires that economic actors are able to cleanly 'disentangle' goods or instruments that are to be traded from their broader social context, thus rendering them calculable (Caliskan and Callon 2010). Not only do markets require legal and institutional processes to enable calculation, but also shared knowledge among market participants as to how goods should be evaluated (Carruthers and Stinchcombe 1999). As a consequence, to date the SSF has largely focussed its attention on how market participants – such as traders – use devices, formulae, and various technical practices to determine the price or assess the value of financial instruments and thereby contribute to the construction of a stable market 'frame' (c.f. MacKenzie and Millo 2003; Beunza and Stark 2004; Preda 2006; MacKenzie 2011).

Yet with several notable exceptions (c.f. Muniesa, et al. 2011; Lepinay 2011; Milyaeva 2014), the role of collateral, legal knowledge, and other 'back office' technicalities have been something of a conceptual blind spot for the field. In fact, one of the most forceful criticisms of the SSF to date — which has been articulated by Riles (2010) — is the field has largely ignored important technical practices outside the 'front office'[1] of financial institutions, such as the legal practices underpinning the exchange of collateral. Riles claims that in doing so, the SSF has produced a distorted account of modern finance, which reduces it to a cluster of epistemic activities, thereby reproducing financiers' own culturally-situated beliefs about finance itself. Riles (2011) notes that for Callon (1998), the function of property law is to 'disentangle' objects to a sufficient degree so that they may be bought, sold, and transferred to other parties, thus rendering them calculable, a view that is perhaps not dissimilar from that of many front office traders who see collateral exchange as a mere 'back office' activity that underpins the real substance of finance: the buying, selling, and valuation of securities. Yet close inspection of the work of lawyers within the 'back office' of large banks – as Riles does in her ethnography – reveals that collateral exchange is a more complex cluster of practices than existing perspectives suggest: rather than simplifying or 'disentangling' the relationship between derivatives counterparties, the use of collateral instead tends to raise more ambiguities and complexities than it forecloses.

While Riles is correct that it is a mistake to reduce collateral to a set of practices that merely 'simplify' or 'disentangle' the relationship between market participants, I want to suggest that the SSF's epistemic vantage point is useful in making sense of the emerging epistemic role of collateral in the interest rate derivatives markets since the financial crisis. How, then, can the SSF contribute an account of financial market practice that adds to these existing perspectives but which doesn't unnecessarily 'discount' or oversimplify the significance of taken-for-granted elements such as collateral? I want to suggest that it is useful to view both banks' 'front office' pricing models and valuation practices, as well as the 'back office' techniques underlying collateral exchange, as forms of infrastructure in the tradition of infrastructure studies within STS (c.f. Star and Ruhleder 1996; Star 1999; Bowker and Star 2000). The upshot of such a perspective, I suggest, is that it not only sheds light on how certain elements of finance – e.g. collateral – come to be taken-for-granted and thus treated as infrastructure by communities such as traders and quants, but also how these infrastructural relations can change in the wake of unexpected events like financial crisis.

What the STS literature classifies as 'infrastructure' is characterized by several distinctive features that help illuminate the changing nature of collateral since the 2008 financial crisis. First, beginning with some of the earliest STS work on infrastructure, the term has encompassed not only physical artefacts – such as computer hardware, telephone cables, or roads – but also a broader array of supporting elements including forms of organization, laws and regulations, and even accounting practices (see Hughes 2012). Thus from an ontological standpoint, the term 'infrastructure' does not suggest the notion of a seamless whole, but instead suggests a disjunctive patchwork of – sometimes precariously – interlinked technical and non-technical artefacts and practices. Disjunction is a salient characteristic of physical infrastructural systems; yet it also one of legal systems: A key insight of the sociology of law is that law itself tends to be characterized by contradicting and ambiguous principles and concepts (Halliday and Carruthers 2009, 18). The heterogeneous character of infrastructure is reinforced by its tendency to develop in a path-dependent manner. As Star (1999, 382) notes, infrastructure 'does not grow *de novo*'; instead, new components are built upon a pre-existing installed base. Moreover, it 'is fixed in modular increments, rather than all at once globally' (382). This is certainly the case with financial models that are embedded within software infrastructure; but it is also true with collateral infrastructure, insofar as collateral exchange is a predominantly legal activity, and UK and US courts – the two legal venues which govern most derivatives collateral agreements – are generally required to follow established precedent.

Perhaps the single most salient feature of infrastructure is that it tends to be simultaneously important yet taken-for-granted, overlooked, and even invisible to its users (Star 1999, 382). In the case of everyday infrastructures, the inner-workings of the electric grid and the sewage system attract little explicit attention from the vast majority of their users. However, the STS literature has emphasized that whether an object is seen as infrastructure is not an intrinsic feature of the object, but is instead a relational property between the object and a set of organized practices. For Star and Ruhleder, the relevant question is 'when – not what is 'infrastructure?' (Star and Ruhleder 1996, 113). In the context of finance, we can think of infrastructures as being relational to particular 'evaluation cultures': i.e. particular clusters of practices that market participants use to identify the value of financial instruments (MacKenzie and Spears 2014). Practitioners trained to practice such a culture typically learn a particular ontology, or a set of assumptions, about what factors are 'relevant' to the valuation of financial instruments which enables coordination among practitioners. What counts as 'infrastructure' to practitioners of that culture typically maps on closely to this learned ontology. The relationality of infrastructure has an additional effect: Because work that involves the creation and maintenance of infrastructure generally tends to be regarded as having relatively lower status (due to the tendency of objects treated as infrastructure to be invisible), infrastructural relations tend to engender not only status hierarchies but also organizational and cognitive divisions between the builders and users of infrastructure (Shapin 1989). Within contemporary financial institutions, this relational property of infrastructure reflects patterns of status stratification among employees, with some forms of financial work (e.g. that of the 'back office' collateral lawyers examined by Riles) being valued significantly less than others despite their importance to the day-to-day functioning of the organizations.

Moreover, infrastructures are capable of embedding and reproducing the assumptions, practices, and beliefs of their designers and users, as well as 'spinning out' new social relations between them (Jensen and Morita 2017). In some of the earliest STS work on infrastructure, for instance, Star emphasized that learning how to use and subsequently take for granted a system of infrastructure tends to be an important part of becoming socialized into a given community of practice (Star 1999). As such, infrastructure serves as an anchor through which a community or culture's values and practices are reproduced through time and space. Recent work within the SSF has shown how explicit moral and political orders become embedded within infrastructure. Focusing on the invention of the electronic order book – what has now become an essential piece of financial infrastructure in the global equity markets – Pardo-Guerra (2012) shows how the device embedded a particular moral order grounded in the Calvinist beliefs of its inventor, Frederick Nymeyer. While the infrastructures that I focus upon in this paper do not carry such explicit moral overtones, they nevertheless embed and reproduce specific assumptions about how markets operate. In this respect, while early work within the SSF was theoretically grounded in actor-network theory rather than the concept of infrastructure, it made similar insights about the capacity of material devices – such as financial models – to embed assumptions or theories about how markets behave within markets themselves (c.f. MacKenzie 2006).

Infrastructure is also prone to failure, which creates risks for its users. Indeed, as a growing body of work in anthropology has shown, infrastructure is paradoxical in this respect: Even though infrastructures are typically developed to ameliorate particular risks, the more a given piece of infrastructure becomes taken for granted, the more difficult it becomes to anticipate its failure, or how its failure will impact seemingly unrelated infrastructural components (Howe et al. 2016, 556). One source of failure is the materiality of infrastructure: Even a seemingly immaterial object like an algorithm requires a material medium – e.g. computer hardware – to operate. As a consequence, infrastructure must be regularly maintained, work that tends to be overlooked by its users by virtue of infrastructure's relational character. This is certainly true with familiar forms of infrastructure such as roads and levees, which must be constantly repaired to remain operational. But this property also characterizes more abstract forms of infrastructure, such as computer software at a bank. With time, computer code becomes 'stale' and bug-prone, and software developers (including the quants discussed in this article) must constantly 'refactor' (i.e. re-engineer) a codebase to prevent such errors from accumulating. Even legal infrastructure – such as the collateral agreements examined in this paper – must be updated to take into account the changing regulatory and legal landscape in which banks operate. Second, the relationality of infrastructure can both amplify and hide these risks. As Larkin (2013) notes, infrastructures are defined not only by their components, but also the way these components are connected. Infrastructures are thus at once 'things', but 'also the relation between things' (Larkin 2013, 329). This property of connectedness is what allows infrastructures to enable coordinated action across space, organizational boundaries. Yet this property, combined with their tendency to be overlooked by their users, means that a reconfiguration or a failure in one component of infrastructure can have wide-reaching – and initially invisible – effects on other seemingly unrelated components, and consequently, the social relations between those who rely upon the infrastructure. However, unlike physical infrastructures, where the risk of failure tends to translate into outright danger, the failure of financial infrastructures can create arbitrage opportunities, and thus opportunities for profit for market participants who are able to identify such failures. Market participants who can identify a misalignment between two infrastructural components may be able to engage in a form of arbitrage that is initially difficult for other market participants to identify specifically because it involves taken-for-granted elements of finance. This form of arbitrage is made possible by the fact that financial infrastructures often play a dual role within banks, in line with recent work within valuation studies. François Vatin (2013) has argued that the practice of 'valuation' should be examined as two distinct activities: 'evaluation' on the one hand, which involves making assessments or judgments about the worth of an object (for instance, a financial security), and 'valorization', which involves the creation or generation of that object's worth. The social studies of finance has, in line with its traditional orientation towards studying the 'front office' infrastructures of finance, primarily focused on infrastructures of evaluation. Yet within finance and in the derivatives markets in particular, financial infrastructures are also constitutive of the value of financial securities. In contrast to physical goods, OTC derivatives – such as the 'capital guarantee products' examined by Lépinay (2011) as well as the interest rate derivatives I examine here – amount to contingent promises made by the bank selling the derivative. A range of infrastructures is needed to ensure that the bank is able to meet these promises, including trading and legal infrastructures. Yet because financial infrastructures can affect the worth of securities like derivatives in unseen and unexpected ways, inconsistencies between infrastructures underpinning processes of evaluation and valorization can create profit opportunities for those able to identify them.

Consistent with this perspective, in the remainder of this paper I examine the development of two clusters of practices that are relational to the 'evaluation culture' practiced by derivatives quants. These infrastructures are the mathematical techniques used to 'discount' (i.e. value) derivatives cashflows at LIBOR, and the legal practices underlying the exchange of collateral. During the financial crisis, traders at a small group of banks realized that LIBOR no longer accurately captured the funding costs of banks participating in these markets and engaged in a form of infrastructural arbitrage to profit from other banks' ignorance of this fact. This episode of infrastructural arbitrage led banks to rebuild their modelling infrastructure to take the details of collateralization into account. However, rather than stabilize these markets, the discovery by quants and traders of the once ignored legal details of collateral – and the incorporation of these details into their own culture of modelling – has instead created additional evaluative uncertainty, which has affected the liquidity and transparency of these markets in the last several years.

Sources

The historical account described in this article has been developed from three main sources of data. The first is a corpus of news articles, technical papers, and books published between the early 1980s and the present day. Many of these articles were published in *Risk* – a prominent trade journal within the interest rate derivatives market – that reported changes to banks' derivatives modelling practices between 2008 and 2016. When taken together, these publications permitted the historical reconstruction of banks' modelling practices over time. The second source is a set of eighteen interviews[2] that were conducted between 2011 and 2013 with mid and senior-level derivative quants, former traders, and other interest rate derivative market practitioners that addressed the development and adoption of the modelling practices discussed in this article. Because these developments were ongoing when these interviews were conducted, the primary focus of these interviews was to understand, in general terms, how the use of models used by quants and traders within dealer banks have changed over time, how these models and practices are situated within the organizational structure of the bank, and how they have changed over the individual's career in banking.

In addition to these eighteen interviews, this paper indirectly draws upon a broader sample of twenty-one interviews that were conducted with derivatives quants, financial mathematicians, and financial economists that did not specifically cover the development of the modelling techniques covered in this article, but were useful in understanding and reconstructing the broader practices of quants.

Finally, these interviews and documents were supplemented by ethnographic fieldwork conducted at three week-long derivatives quant conferences in 2012, 2013, and 2014. These instances of fieldwork provided insight into the adoption and use of these modelling techniques within the quant community since the financial crisis.

LIBOR Discounting as Modelling Infrastructure

Because the empirical focus of this article is the markets for interest rate derivatives that are traded on an OTC basis, it will be helpful to begin with a general overview of the structure and function of these markets within the global financial system before examining the legal and modelling practices used within these markets. OTC derivatives are customized financial instruments that involve the exchange of cashflows between two parties over months or years for both speculative and hedging purposes. In contrast to exchange-traded derivatives, OTC derivatives are privately negotiated. Typically one party to a derivative contract will be a 'dealer bank', i.e. a large international bank that 'makes markets' in OTC derivatives. As 'market makers', traders at these banks stand willing to enter into these contracts with organizations such as corporations, other financial institutions, or government entities and then hedge (i.e. reduce or eliminate) the resulting financial risks by trading in simpler financial instruments. Within these banks, 'quants' are employed to build and maintain mathematical models to price and hedge these instruments. It is the modelling practices of these quants that are the empirical focus of this article.

Interest rate derivatives are a subset of OTC derivatives that are designed to allow market participants to hedge against – or speculate upon – changes in market interest rates. Prior to the financial crisis, most interest rate derivatives referenced LIBOR, a set of rates that are designed to measure the interest rate at which large banks (many of which are derivatives dealers themselves) are willing to lend each other money on an unsecured basis for certain intervals of time up to a year. A market for LIBOR derivatives first originated in the early 1980s in London and New York, but have since become one of the largest OTC derivatives markets in existence (Beckstrom 1986). According to statistics provided by the Bank for International Settlements, interest rate derivatives make up approximately seventy-eight percent of total notional issuance of OTC derivatives globally,[3] while a trade-level analysis of these markets conducted by Fleming et al. (2012) suggests that interest rate derivatives written on LIBOR made up the majority of these contracts even in the years following the financial crisis.

Following the emergence of these markets in the early 1980s, banks' quants adopted and implemented (in the form of software) a set of mathematical models for pricing derivatives that had been previously developed by financial economists. These models had their origin in the Black-Scholes-Merton formula for pricing equity options, a core assumption of which is the existence of a 'risk-free' security that pays interest to investors at the risk-free rate of interest. To use these techniques to price interest rate derivatives, quants combined these models with additional techniques for modelling interest rates drawn from the bond markets. For the purposes of this paper, the most important of these was the use of a 'discount curve' derived from (i.e. 'stripped' from) the market prices for bonds of various maturities in a given currency, and which serves as a representation of the risk-free rate of interest for that currency. For each future date, a discount curve provides the market-implied price of a hypothetical bond that pays £1 on that date and nothing before. By converting quoted bond prices into a smooth curve of implied prices for these hypothetical discount bonds, a bond trader could infer the market-implied price of any unquoted bond by describing its future payments in terms of these discount bond prices. By the mid-to-late 1980s, derivatives quants began to apply this technique to the pricing of interest rate derivatives (Cooper 1987). But rather than 'strip' a discount curve from bond prices, the convention that emerged within these markets was to 'strip' this curve from a combination of LIBOR rates and the fixed rates quoted on LIBOR-based swaps for longer maturities. (An illustration of a discount curve 'stripped' from a set of LIBOR and swap rates is provided in Figure 1.) Yet this choice made an implicit yet critically important assumption: by using LIBOR to discount future swap cashflows, this practice assumed that the bank itself – and indeed, all banks that make up the swaps market – could borrow and lend money on a short-term basis at LIBOR.

Due to its epistemic importance for a dealer bank's interest rate derivatives trading operation, the LIBOR discount curve came to serve as a key piece of informational infrastructure that circulated within the trading floor of banks prior to the financial crisis. Within the trading floor, the responsibility for 'creating' these curves was typically the responsibility of the bank's interest rate trading 'desk':[4] the subset of the bank's traders responsible for 'making markets' in instruments such as bonds, swaps, and interest rate futures. In turn, these traders depended upon software written by the bank's quants that could transform a small number of quoted swap rates into a continuous discount curve. From a technical standpoint, developing the software needed to build a set of discount curves is not a trivial exercise. The development of effective algorithms capable of quickly and accurately 'stripping' a set of discount rates from market prices requires a number of crucial choices that can, in principle, profoundly affect the way in which the value and risk of a bank's derivatives positions are measured and represented. 'Nathan', a head quant at a major French bank, stressed this explicitly in an interview: 'The way you construct the [discount] curve has a phenomenal impact on the way you see the risk to changes in the level of the curve'. Thus while the practice of using a discount curve was widespread, if not universal, among dealers, every bank's curve building system was, to some degree, distinct, particularly with respect to how gaps in the curve were interpolated between points (Sadr 2009, 124).

Despite this complexity, traders and even many quants generally viewed discount curves as mundane informational infrastructure prior to the financial crisis: taken-for-granted albeit necessary devices that are used as inputs into more complex financial models. Indeed, by the early 2000s, the technology and know-how needed to build and use a discount curve had long become ubiquitous among banks, and descriptions of the techniques needed to do so were widely published in journal articles and introductory textbooks on mathematical finance (c.f. Brigo and Mercurio 2006; Hagan and West 2006). Writing and maintaining the software needed to build LIBOR curves thus came to be seen as boring, low-status work within the profession. 'Eugene' compared the quants who were responsible for the construction of discount curves prior to the crisis as the financial equivalent of a bank's janitorial staff:

> Eugene: I think probably when I was first at Barclays, the QA Linear - as they called it - was probably ten people globally. And the guy running it was not a particularly senior guy. And indeed, the guy running it reported to the head of exotics […] The point is the linear group was a small group that probably didn't, you know… [the head of exotics] probably didn't have in mind that they were where he spent thirty percent of his time.
>
> Author: Yeah?
>
> Eugene: It was one of those things that… It's like the people who hoover the carpet, or something. That sounds really derogatory, but you know what I mean. It's like the coffee machine; it's just always working, hopefully.[5]

ISDA, CSAs and the Legal Infrastructure of Collateralization

While the assumption that all derivatives market participants could borrow and lend money at LIBOR was initially a reasonable one, with the rapid growth of these markets throughout the 1990s banks increasingly began to collateralize derivatives transactions – typically with cash or low risk government bonds – in order to guard against the risk of a large dealer bank defaulting on its payment obligations. This, in turn, gradually created an inconsistency between two infrastructural components that were easily overlooked by front office traders: on the one hand, the software built to ‘strip’ a LIBOR discount curve; on the other, the back-office practices that underlay the exchange of collateral.

The impetus to collateralize OTC interest rate derivatives was as much political as it was pragmatic. From a pragmatic standpoint, the need for collateral grew as the diversity of participants in the market increased. When these markets first emerged, almost all dealers that participated in these markets were regarded by other market participants as having a low degree of credit risk, a belief that was embedded within the modelling infrastructure created and used by front office quants and traders. But as the market expanded in size, a greater number of organizations began to participate, many of which were characterized by lower credit ratings. Moreover, the late 1980s were characterized by a wave of ratings downgrades among banks and other derivatives dealers (Torres 1991). Because derivatives clients, such as corporations, were very reluctant to trade with banks perceived as having non-negligible levels of credit risk, low rated banks began offering to back their derivatives agreements with collateral, either in the form of cash or highly-rated government bonds (Lee 1995).

In time, financial regulators came to explicitly encourage the use of collateral among all market participants as a way of ameliorating what they perceived to be a growing quantity of credit risk accruing on banks’ balance sheets. Indeed, between 1981 and 1986, the notional value of OTC derivatives outstanding grew from essentially nothing to around $400 billion USD (Whittaker 1987, 7). While traders could, in principle, hedge away many of the market risks of OTC derivatives by trading in instruments with off-setting cashflows, there was no straightforward way, at that time, to hedge against the risk that a bank’s trading partner might default on its payment obligations. The use of collateral or other financial guarantees was one of the few mechanisms one could use to substantially reduce the credit risk of an OTC derivative. As Gabor and Ban (2016) note, the use of collateral within European countries was later explicitly encouraged by the EU Collateral Directive, a law that was partially motivated by the desire to promote greater financial integration among EU member countries. Passed in 2002, the Directive requires member countries to allow regulated banks to ‘rehypothecate’ collateral posted to them, and also mandates that all EU member countries recognize the practice of close-out netting in bankruptcy procedures.

Initially, however, there was a great degree of variation among market participants in terms of how derivatives collateralization was practiced. The task of developing standardized legal infrastructure for managing and exchanging collateral ultimately fell to the International Swaps and Derivatives Association (ISDA), the industry association and lobbying group for the OTC derivatives markets. ISDA had previously focussed its efforts on developing what is known as the ISDA Master Agreement, a standardized legal contract that provides a pre-established contract design, terms, and definitions that market participants can customize, in certain limited ways, when establishing a trading relationship (Flanagan 2001; Riles 2011). ISDA later chose to develop an optional supplement to the Master Agreement, known as the 'Credit Support Annex' (CSA) to cover the exchange and posting of collateral, which banks and their clients could elect to use. First released in 1994, the ISDA CSA provides a combination of standardized contractual features that banks and their trading partners would agree to by default, as well as a number of optional choices that the parties themselves would be left to specify, much like the original ISDA Master Agreement. When two parties sign a CSA, each party agrees that when it owes money to the other under a derivative contract (i.e. the contract has a negative value for that party), it will transfer an amount of collateral (e.g. cash or other low-risk assets depending on the terms of the CSA) to the other party equivalent to this amount.

In developing the CSA, ISDA faced a number of competing pressures, which influenced the design of the collateral protocols it developed, and which would ultimately prove fateful in engendering complexity in the wake of the 2008 financial crisis. First, the practices developed by ISDA had to be able to accommodate the diverse preferences of the participants that make up these markets (Flanagan 2001). When negotiating a CSA, banks and their trading partners were given significant leeway in deciding what types of collateral each party would be permitted to post (e.g. cash in a variety of currencies, government bonds, or stocks),[6] the maximum percentage of each type of collateral that could be posted, and any thresholds for the value of the derivative under which collateral would not be required.[7] Perhaps more importantly for this article, banks and their trading partners had to agree, for each of these types of collateral, the interest rate benchmark that would be used when calculating accrued interest on posted collateral, as well as whether collateral posted by each party could be 'rehypothecated' by the other (i.e. reused as collateral for some other transaction). Finally, because OTC derivatives are traded across national borders, banks and their counterparties were free to choose the legal system that would govern the exchange of collateral for a given derivative. (The two most popular choices were English Law and New York Law).

Within banks, the negotiation of a bank's CSAs and the management of collateral — what was predominantly seen as a 'back office' activity — were tasks that were both organizationally and cognitively separated from the development of a bank's derivatives pricing models. Similar to the LIBOR discount curve, which became treated as a taken-for-granted piece of infrastructure by most traders and quants, so too did the practices underlying collateral exchange. However, this tendency to 'black-box' collateral was further driven by the lack of a shared culture between front and back offices. Understanding the details of a CSA requires specialized training in ISDA's own transnational system of private law, which relatively few lawyers, let alone quants or traders, possessed. (Even now ISDA routinely runs specialized workshops to train lawyers in the particularities of Master Agreement and CSA negotiation.) When asked who on a derivatives quant team is responsible for understanding the contents of a bank's CSA agreements, ‘Stephen’, a head quant of a major American dealer bank, explained in an interview that understanding these documents was the responsibility of the banks’ lawyers, who were specialists in what he called ‘ISDA law’:

> Author: Out of curiosity, who on a quant analytics team - well, these issues about ISDA collateral agreements, they strike me as being both related to valuation and very much related to the law. And I would imagine that very few quants have legal training. [Stephen: Right.] So who in the bank deals with this stuff?
>
> Stephen: Well, there’s a set of lawyers who do that. I mean, all the banks have lawyers who specialize in ISDA law, and also when it comes to capital, and all that. I mean, these are legal documents, so we have securities lawyers to formulate that.[8]

‘Robert’, a head quant at a major European dealer bank, explained quants’ relationship to the legal technicalities of collateral a bit more bluntly: ‘Very few people understand those documents. And it’s a legal document, right? It’s like pulling teeth trying to read those things.’ Another reason for this separation was the fact that the use of collateral was not primarily designed to address valuation and pricing problems facing quants and traders in the front office; instead, it was motivated by the need to protect financial institutions' from the costs and uncertainties of the bankruptcy process. ‘Jack’, a former ISDA law specialist, emphasized in an interview that the major benefit of using collateral is that it allows one to avoid the bankruptcy process in the event that one's counterparty defaulted on its derivatives: ‘Someone who is owed £10 and is holding collateral at £10 can just take the collateral. […] And that’s very important because – bankruptcy is messy. So you don’t want to be involved in it.’[9]

This separation between the practices of valuation and financial modelling on the one hand and collateral exchange on the other was also a practical implication of the temporality of trading *vis-a-vis* collateral negotiation. In the front office, a bank’s traders may execute dozens or even hundreds of different derivatives contracts with a given counterparty, each of which must be priced. In contrast, within most banks, the negotiation of a CSA occurs once when a trading relationship with a new counterparty is first being formed. ‘Alan’, a former swaps trader who now runs a hedge fund, explained that the negotiation of a CSA typically takes place during what is known among bankers as the ‘Know Your Client’ (or ‘KYC’) phase of the creation of a new trading relationship, in which a bank might examine the financial statements of a potential new counterparty and conduct an onsite examination for due diligence purposes. Negotiating a CSA is thus a costly exercise that, if possible, is not to be repeated frequently. ‘Brandon’, a counterparty risk specialist, explained to me in a 2013 interview that negotiating a CSA typically takes around two weeks. During this time, both parties ‘lock their lawyers in a room and pay them until they agree on a contract’.[10]

The Impact of the Financial Crisis

Although LIBOR discounting and the ISDA CSA both became largely taken-for-granted infrastructure within banks' front offices, quants and traders at a small number of banks realized that the use of a CSA is not simply a risk mitigant; it also should, in principle, alter the value of an OTC derivative, thus making the use of a LIBOR discount curve, from a theoretical standpoint, an inappropriate choice.

To appreciate why, consider a simple bond in which one bank (A) agrees to pays another bank (B) £100 in one year's time.[11] How much should B be willing to pay for this bond today? Suppose that B valued this future promise to pay using a LIBOR discount curve, and that the current one year LIBOR interest rate is currently 5%. In that case, the present value of the promise would be worth approximately £95.23. Now, suppose further that A agreed to collateralize the bond under a CSA. In this case, immediately after selling the bond and receiving payment, A would transfer the £95.23 back to B as a pledge against the value of the bond. However, if the terms of the CSA do not require that the bond's collateral accrue interest at LIBOR, then in one year's time there will be a mismatch between the value of the collateral held by B and the value of the bond payment owed to B by A. To avoid such a mismatch, a collateralized instrument should — this logic suggests — be discounted not at LIBOR, but at whichever interest rate is specified in the CSA agreement itself. In the case of CSAs that only allow cash collateral, this typically entails discounting the derivative's cashflows by a set of interest rates derived from quotations from what are known as 'overnight index swaps' (OISs), a set of interest rate swaps that pay the average of an overnight interest rate over a given number of months or years.

Prior to the financial crisis, the difference between LIBOR and the interest rates specified in most collateral agreements was quite small. In the case of Euribor (a variant of LIBOR for borrowing in Euros), the average 'spread' (i.e. difference) between it and the relevant overnight borrowing rate was 6 basis points — or .06 percent — for the period between mid-2005 and mid-2007. While awareness of this effect was limited among traders and quants prior to the crisis, there is evidence that some traders recognized the effect as early as the mid-1990s and incorporated it into the prices they offered to market participants. Indeed, one of the first published papers to acknowledge the impact of collateralization on derivatives pricing was written by Michael Johannes and Suresh Sundaresan (2007), two finance academics at the Columbia Business School. In their paper, they find evidence that the quoted swap rates (the equivalent of a price for an interest rate swap) reflected a partial awareness of this effect as early as the mid-1990s. Yet at banks where the effect was recognized, traders likely incorporated it into the prices they offered in an ad-hoc manner (i.e. by making adjustments to prices implied by LIBOR discounting), rather than by formally changing the bank's own valuation infrastructure. Indeed, due to the small size of the effect, LIBOR discounting continued to work sufficiently well long after the legal infrastructure underlying collateral exchange became commonplace within banks.

As Cameron (2013) notes, one of the first banks to redevelop its derivatives pricing infrastructure to account for the effect of collateral was Goldman Sachs. By the early 2000s, quants and traders within the bank realized the theoretical need to replace the practice of LIBOR discounting with a valuation technique that could account for the specific features of the bank's CSA with a given counterparty. According to Cameron (2013), by 2005 the bank launched an internal project to rebuild its valuation infrastructure to take these effects into account. In doing so, quants at Goldman Sachs built a system that essentially merged the front office derivatives pricing infrastructure with the back office infrastructure that kept track of the bank's CSA agreements: The system was capable of taking various pieces of information from the CSAs that the bank had signed with its counterparties and, using this information, could build a counterparty-specific discount curve to be used when pricing derivatives with that counterparty (Cameron 2013, 16).

Yet Goldman Sachs's timing in this respect proved to be extremely fortuitous. The credit crisis that began in mid-2007 with a run on the securitized 'repo' markets led market participants to become increasingly skeptical of the solvency and liquidity of large banks (Gorton and Metrick 2012). As the crisis then spilled over into the market for unsecured bank lending, banks became increasingly unwilling to lend to each other out of the fear that other banks would default on their loans, a fear that became manifest in the form of higher interest rates when borrowing in the unsecured money markets. As a consequence, a large spread emerged between LIBOR rates across the major currencies and the overnight interest rates specified in most banks' collateral agreements. The emergence of this spread is illustrated in Figure 2.

Traders at Goldman Sachs and a small number of other banks saw an arbitrage opportunity in the midst of the crisis that involved exploiting inconsistencies between two taken-for-granted but increasingly misaligned pieces of financial infrastructure: the modelling infrastructure of LIBOR discounting on the one hand, and the legal infrastructure underlying the exchange of collateral. A trader could thus approach his/her counterpart at another bank that still used LIBOR discounting and offer to pay a certain amount of money to take over his/her position on an existing swap. The offer would be designed to *appear* profitable under that bank's own valuation infrastructure (which used LIBOR discounting), but was actually loss-making when CSA discounting was used to value the trade.[12] As Cameron (2013) notes, because the trade would be collateralized, the money paid to the other bank would then be immediately posted back to Goldman Sachs as collateral, which it could then rehypothecate for its own purposes. It was a way to profit from a discrepancy in the pricing of swaps and other interest rate derivatives, during a time of crisis, in a manner that required no upfront capital for the bank: in effect, an arbitrage. Based on interviews with traders involved in the arbitrage at Goldman Sachs, Cameron (2013) estimates that the bank was able to post approximately $1 billion USD in profits from these activities.

CSA Discounting as Modelling Infrastructure

Others soon caught on to Goldman's strategy: By early 2008, derivatives quants and traders at other dealer banks began to realize the effects of collateral on the valuation of interest rate derivatives, particularly in the wake of the financial crisis (Interviews with Joshua, Eugene). As a consequence, many banks rushed to rebuild their own internal valuation infrastructures to quickly capture these effects on the pricing of interest rate derivatives. By 2010 the use of OIS discounting had become sufficiently widespread within the market that *Risk* had declared the practice a new 'market standard', even though it had not yet been fully adopted by all banks (Whittall 2010a).

Among quants, however, the credit crisis and the resulting collateral arbitrage did not expose a mere technical problem with banks' derivatives valuation infrastructures. Instead, it challenged the intellectual foundations of derivatives pricing theory at a more fundamental level. LIBOR's reliability as a measure of the cost of unsecured borrowing among large banks was rarely questioned when Goldman Sachs began rebuilding its pricing infrastructure to take the effect of collateralization on derivatives pricing into account. Yet by mid-2008, rumors were circulating within the derivatives community that some banks had been understating their true costs of borrowing in the interbank money markets out of fear that a high value for LIBOR might cripple their own solvency (Madigan 2008), a belief that was later shown to be true during the investigations of potential manipulation of LIBOR. The credit crisis also led market participants to differentiate between the credit and liquidity risks *between* banks (rather than simply between secured and unsecured loans of all banks), which meant that each bank was soon able to borrow money at different interest rates. This change is reflected in publicly available data on banks' own LIBOR submissions during that time. As Figure 2 illustrates in the case of Euribor, beginning in 2009 there came to be a large variance in the self-reported borrowing rates among banks on the Euribor panel (illustrated by the light red region surrounding the darker red line), which has remained a persistent feature of the market for many years. It is also a change that is reflected in the credit ratings of the banks that constitute the LIBOR panels, as illustrated in Figure 3. In this environment, LIBOR's facticity increasingly came into question: no longer a reliable approximation of *the* rate at which large banks could borrow money on an unsecured basis, it was rapidly evolving into a mere *average* of the rates at which banks could borrow. And for a given bank, the difference between LIBOR and its own borrowing costs could now change rapidly depending on market conditions.

LIBOR’s fall from grace thus led not only to changes in the infrastructure of interest rate derivatives trading, but also created something of an intellectual crisis within the derivatives quant community, given that – as mentioned in Section 4 – a fundamental assumption of the style of derivatives pricing theory that had originated with Black-Scholes-Merton model was the assumption of a risk-free rate of interest at which all participants in the market borrow/lend cash. In the Black-Scholes-Merton model, for instance, a risk-free asset is needed to construct the replicating portfolio needed to both price and hedge a stock option. Yet in a world where every bank must pay a different interest rate to borrow money on an unsecured basis, the logic of Black-Scholes would intuitively suggest that every bank should assign a different valuation to a given derivative. Vladimir Piterbarg, who was at the time the head of Barclays’s quantitative analytics department, published an influential paper in *Risk Magazine* that rebuilt the Black-Scholes-Merton model for a world in which banks could no longer borrow and lend money at a single risk-free rate (Piterbarg 2010). While Piterbarg’s paper provided a formal proof justifying the emerging practice of discounting the cashflows of collateralized derivatives at the relevant OIS rate – as Goldman Sachs's traders and quants had discovered – it also suggested that when a derivative is not collateralized, its value would now depend upon the funding cost of the bank selling the derivative, a notion that remains controversial to this day among quants and finance academics (c.f. Hull and White 2012; Atan and Saunah 2012). More problematically, this funding cost is – by definition – unobservable to all market participants except the bank selling the derivative itself.

As economic sociologists have long noted, the capacity of market participants to reach agreements about the value of goods and instruments is dependent their capacity to engage in what Espeland and Stevens (1998) refer to as ‘commensuration’ between similar goods: that is, to compare their value according to a common metric. The downfall of LIBOR and the divergence of banks’ borrowing costs thus threatened the capacity of participants in these markets to establish equivalences between the value of derivatives sold by different banks. As a solution to this problem, quants and traders eventually adopted a new market convention: the value of a derivative traded under a simple CSA (in which collateral could only be posted in a single currency; what ‘Robert’ referred to as a ‘Gold Standard CSA’ and others referred to as a ‘clean CSA’) would serve as a benchmark for the market price of *any* OTC derivative. The value of an uncollateralized derivative could then be calculated by making a series of valuation adjustments to this market standard benchmark. ‘Paul’, a quant at a large American dealer bank, explained in an interview that the value of this collateralized derivative is now treated as a *de facto* measure of the derivative’s market price:

> [W]e’ve tried to separate it into two problems. One is you say, “What’s the market standard for the deal?” So right now the market standard is discount at OIS in the currency of the deal.

> [Author: Hmm.] That's the market standard - so when somebody asks me the market price, that's what I give them. Now if I have a special agreement with you, then I'm going to have a [valuation adjustment], because it might be - I have a different collateral agreement with you which makes the deal a little bit different, or you might be an end user or corporate or something that doesn't post collateral.

The Hidden Complexity of 'Dirty' CSAs

Thus by 2012, both the practices of discounting and collateral exchange had ceased to be taken-for-granted infrastructures and instead had become objects of active focus for derivatives quants. Eugene, who had noted that prior to the crisis quants perceived the labor of writing software to build the bank's discount curves as akin to janitorial work, later noted in our interview that after the crisis, '[I]t's completely topsy-turvy, in that the sort-of interest rate exotic group is still important, but not nearly as important. The big group is all the curve stripping and so forth.'

But the inclusion of collateral knowledge into quants and traders' own practices has led to profound changes in quants' modelling culture: that is, an expansion of the socio-technical elements seen as relevant and important to the valuation of interest rate derivatives. This, in turn, has led to an explosion of complexity in the valuation of even the simplest interest rate derivatives. Indeed, quants began to realize that valuation becomes substantially more complicated when one considers the full range of flexibility that the ISDA CSA gives to financial institutions when negotiating the terms of collateral exchange, something that banks' quants and traders had ignored prior to the crisis. As noted in Section 5, banks and their counterparties are free to specify — among other things — *multiple* types of collateral that can be posted by each counterparty. In addition to various currencies, these might include government bonds from one or more countries, or even stocks. And depending on the legal jurisdiction of the CSA, the contract might allow one or both of the parties to substitute collateral: that is, to swap out one form of collateral for another at any point in the life of the derivative contract. Because of their training in the no-arbitrage modelling techniques that originated with the Black-Scholes model, quants came to view this potential right to substitute collateral through a cultural lens that was largely unfamiliar to many of the ISDA lawyers who had originally negotiated these agreements: they viewed these substitution rights as 'switch options' analogous to the stock options that the Black-Scholes model had been developed to price (Sawyer 2011).[13] When I asked 'Robert', the head quant at a European dealer bank, about these 'switch options' in an interview that was conducted in March 2012 (a time when many of the new valuation conventions were still solidifying), he noted how awareness of this optionality only became apparent to quants when they started to interact with the details of ISDA's legal practices more closely:

> Current market practice changes, right now, like day-to-day. So, kind-of two years ago, people were thinking - "Yeah, collateralized trades, OIS, very easy". Now actually they are starting to look at details of those CSAs, the credit support annex, which is part of the legal documentation. And they find things there actually have a profound impact on valuation, but we haven't been taking it into account. […] We thought OIS, but then you realize you can deliver different types of collateral. And it's actually economically preferable to choose one and they aren't equivalent, and so you can always choose which one, and so it is becoming very, very complicated.[14]

The recognition of these switch options has contributed to a new form of trading activity known as collateral optimization: Determining, on a day-by-day basis, the cheapest form of collateral one can post to one's derivative counterparty, constructing a sequence of trades to borrow that collateral in the most cost-efficient manner possible through the repo and foreign exchange markets, and then delivering it to the counterparty. In addition to creating greater operational complexity, the presence of these switch options has also dramatically increased the analytical complexity of valuing even the simplest of interest rate derivatives (Cameron 2012). Before the crisis, a single discount curve could be used to price an instrument such as a swap, regardless of whether it was collateralized. Following the crisis, however, a collateralized swap which – for example – is traded under a relatively simple CSA that allowed collateral to be posted in three different currencies would require at least fifteen separate discount curves to be priced.[15] These complexities, in addition to those associated with the valuation of uncollateralized derivatives mentioned previously, have greatly increased the opacity of the interest rate derivatives markets since the financial crisis. As a consequence of this newly discovered collateral optionality, a market participant requesting a price for even a simple derivative will receive a different price from each bank depending on the precise features of the existing CSA between the bank and that participant.[16]

In recent years, ISDA and various derivatives market participants have attempted, with only modest success, to resolve this evaluative uncertainty by adopting new CSAs that remove this optionality by allowing one to post collateral in only a single currency. In 2013, ISDA developed and released what became known as the 'Standard CSA', which as its name suggests, simplifies and standardizes the original CSA. Throughout 2016-2017, banks attempted to force their clients to adopt standardized CSAs as a part of an effort to meet new post-crisis regulations related to the exchange of collateral (Sherif 2016). However, due to the sheer number of 'dirty CSAs' in existence, renegotiating these agreements has proven to be difficult. When I interviewed 'Ryan', a quant at a major Japanese dealer bank in 2012 prior to these developments, he predicted that addressing these problems would be difficult for banks, given that according to the collateral-based valuation practices that have now become standard changing to a new

CSA would mean revaluing the derivative itself. As he said, 'It's thorny business to go back and re-do the old ones [CSAs] because people have booked P&L. They will be resistant to give that up.'[16]

At the time of writing, these collateral-related complexities still exist, as banks have thus far been unable to collectively act to renegotiate their CSAs amongst themselves. According to a July 2016 article published by Becker et al. (2016) in *Risk*, these complexities have contributed to a 30% drop – from $122 trillion to $86 trillion – in the notional value of uncleared derivatives in the last year, with some traders worrying that the market will lose another 90 percent of its volume in the next five years if these agreements cannot be renegotiated (Wood 2016). The irony of the post-crisis evolution of these markets is thus that while banks' modelling practices are now more rigorously integrated with their back office operations, the resulting evaluative uncertainty may bring about the end of the OTC derivatives markets themselves.

Conclusion

Collateral, once discounted as a mere 'back office' technicality to secure financial transactions against credit risk, has become increasingly central to the way that financial instruments are valued and priced. This article has examined the changing role of collateral within the modelling practices developed and used by banks' quants to price interest rate derivatives. Within most financial institutions, the modelling practices used by quants to price derivatives and the legal practices underlying the exchange of collateral evolved independently from one another from the mid-1980s and largely existed as organizationally separate realms of activity prior to the 2008 financial crisis. Since the crisis and the downfall of LIBOR, this historical separation has largely disintegrated, as quants have adopted new practices that value interest rate derivatives according to the properties of the collateral backing derivatives themselves in response to market dislocations caused by the crisis. As a consequence, the previously ignored legal details governing the exchange of collateral between financial institutions have come to influence the pricing of derivatives in profound ways. This has, in turn, contributed to a substantial increase in the complexity and opacity of these markets to a point that now threatens their future existence.

How might we understand this historical episode in the broader context of work within the social studies of finance and economic sociology? In my view, this paper touches on at least two themes that are of relevance to these fields.

The first theme is the relationship between liquidity and abstraction in markets. A long-standing interest within these fields has been the social and material processes that transform heterogeneous, socially-entangled objects – such as houses, artworks, natural resources, and claims of ownership – into commodities with well-defined prices that are traded in liquid markets. While the social studies of finance has largely focused on the role of technical devices, such as mathematical models, in enabling markets to form, economic sociologists have instead focused on the role of law and institutions in this process (c.f. MacKenzie 2010; Carruthers and Stinchcombe 1999). In the interest rate derivatives markets, both technical devices and social processes underpinned the production of liquidity prior to the financial crisis. The mathematical practice of LIBOR discounting allowed traders at different banks to reach consensus about the value of interest rate derivatives by simplifying the valuation of these instruments. It was, in part, *because* it abstracted away from the legal agreements underpinning derivatives trading – in particular, the features of the collateral underlying a given derivative – that LIBOR discounting contributed to the liquidity of these markets prior to the financial crisis. Moreover, under this arrangement, these collateral agreements could be diverse, as collateral was used primarily as a risk management tool. Yet the capacity of LIBOR discounting to contribute to market liquidity depended on a particular set of institutional conditions: that market participants perceived the large banks that 'make markets' in these instruments as being uniformly 'risk-free' from a credit standpoint. Following the crisis, this institutional order broke down and market participants have sought – with only modest success – to make collateral itself the social basis of liquidity by standardizing its features. Collateral has, in effect, taken on a new role as valuation anchor, in addition to its classic role as risk mitigant.

The changing relationship between banks' collateral management and valuation practices touches on a second theme: the importance of organizational and cultural 'breaks' in finance and how they shape financial markets. In her critique of the SSF, Annelise Riles notes that contrary to the vision of actor-network theory – the theoretical approach that implicitly underlies much early work within the SSF – in finance it is often the 'breaks in the network, the points of disconnect and mistranslation' that are constitutive of financial markets (Riles 2010, 796). In recent years, researchers within the social studies of finance have become much more attentive to the importance of these 'breaks' in shaping the behavior of markets. For instance, in Donald MacKenzie's (2010) analysis of the market for subprime mortgage-backed securities, he emphasizes that an inconsistency between the modelling practices used by two organizationally distinct groups within the major ratings agencies led to an arbitrage opportunity that banks exploited *en masse* that contributed to the 2008 financial crisis. Similar to the subprime markets, the separation between banks' modelling and legal practices in the interest rate derivatives markets also engendered arbitrage activity, suggesting that there is a more general connection between arbitrage and organizational structure that could be explored in future research. Yet to date, little work has explored how breaks and inconsistencies between banks' mathematical modelling and legal practices shape financial markets, in part because these 'breaks' often can go unnoticed by financiers themselves.

In this paper, I have suggested that it is useful to view these ‘breaks’ as being constituted by infrastructural relations, which in part define what devices and practices become taken-for-granted by financial market actors depending on their relationship to those devices and practices. In the interest rate derivatives markets, banks’ collateral management and mathematical modelling practices both became treated as taken-for-granted infrastructure among quants and traders, which allowed banks’ collateral management practices to operate according to a logic independent of that of banks’ traders and quants. These markets – and financial markets more generally – are constituted not only by material artefacts and social relations, as the social studies of finance and economic sociology have emphasized, but also the *absence* of relations between particular groups.

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Notes

[1] The term ‘front office’ refers to the portion of a bank or financial institution that contains its sales team, traders, and often the ‘quants’ who build models that are used to price and value instruments bought/sold by the bank.
[2] All names used in this paper are pseudonyms.
[3] Bank for International Settlements (May 2016) “Semiannual OTC derivatives statistics”. Retrieved 3 June 2016, URL: http://www.bis.org/statistics/d5_1.pdf.
[4] A ‘trading desk’ is a unit of organisation within banks that comprises traders who make markets in similar types of financial instruments. It may or may not comprise multiple physical ‘desks’, and is thus roughly analogous to a department.
[5] Interview with ‘Eugene’ in London, 14 March 2012.
[6] Unlike repo or loan markets – where promises are usually secured using real property or government bonds – cash itself is often the preferred form of collateral in the interest rate derivatives markets. For this reason, uncertainties over the valuation of collateral itself does not play a prominent role in the historical episode I examine in this paper, in contrast to the loan and repo markets.
[7] See the 1994 ISDA Credit Support Annex for ISDA Agreements Subject to New York Law, as well as the 1995 ISDA Credit Support Annex for ISDA Agreements Subject to English Law.
[8] Interview with ‘Stephen’ in New York City, 11 April 2012.
[9] Interview with 'Jack' in Washington, D.C. on 22 July, 2011.
[10] Interview with ‘Brandon’ in London, 13 September 2013.
[11] Kenyon and Stamm (2012) provides a simple explanation similar to this in order to justify the practice of OIS discounting. Among quants, the more compelling justification was provided by Piterbarg (2010).
[12] Interview with ‘Nathan’ in London, 3 July 2012.
[13] A presentation by ISDA on the development of a standardized CSA from 2011 states that: ‘Tremendous amount of optionality exists in CSAs. There could literally be millions of combinations of terms. Knowledgeable counterparties should deliver the cheapest form of collateral. […] A CSA is a complex derivative on a portfolio of underlying derivatives, with contingent daily flows of collateral and embedded exotic options’.
[14] Interview with 'Robert' in London, 12 March 2012.
[15] Numerix (2012), ‘Avoiding Collateral Surprises: Managing the Embedded Optionality of Multi-Currency CSAs’, Online Webinar, 4 December 2012, URL: http://nx.numerix.com/rs/numerix2/images/Numerix_Webinar_Slides__Managing_Embedded_Optionality_Multi-Currency_CSAs__Dec_4_2012.pdf.
[16] Interview with ‘Ryan’ in London, 30 November 2011.

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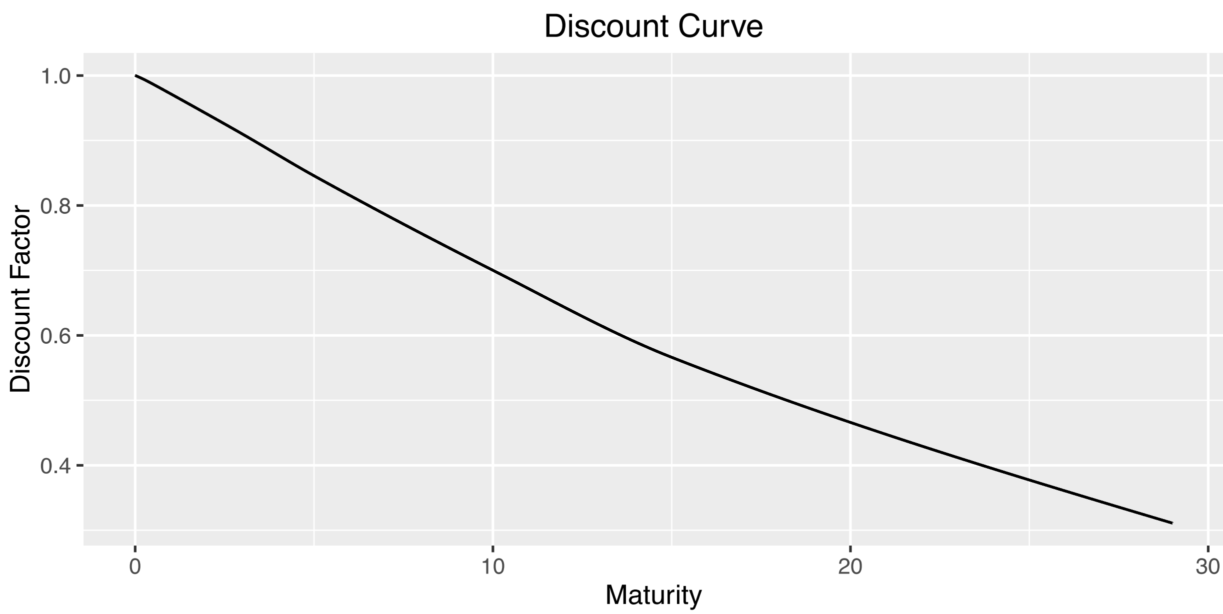

Figure 1: Example Discount Curve. This curve was constructed using EURIBOR rates and the fixed rates of EURIBOR swaps quoted as of 31 January 2006 and curve-stripping code provided by the QuantLib open-source quantitative finance library.

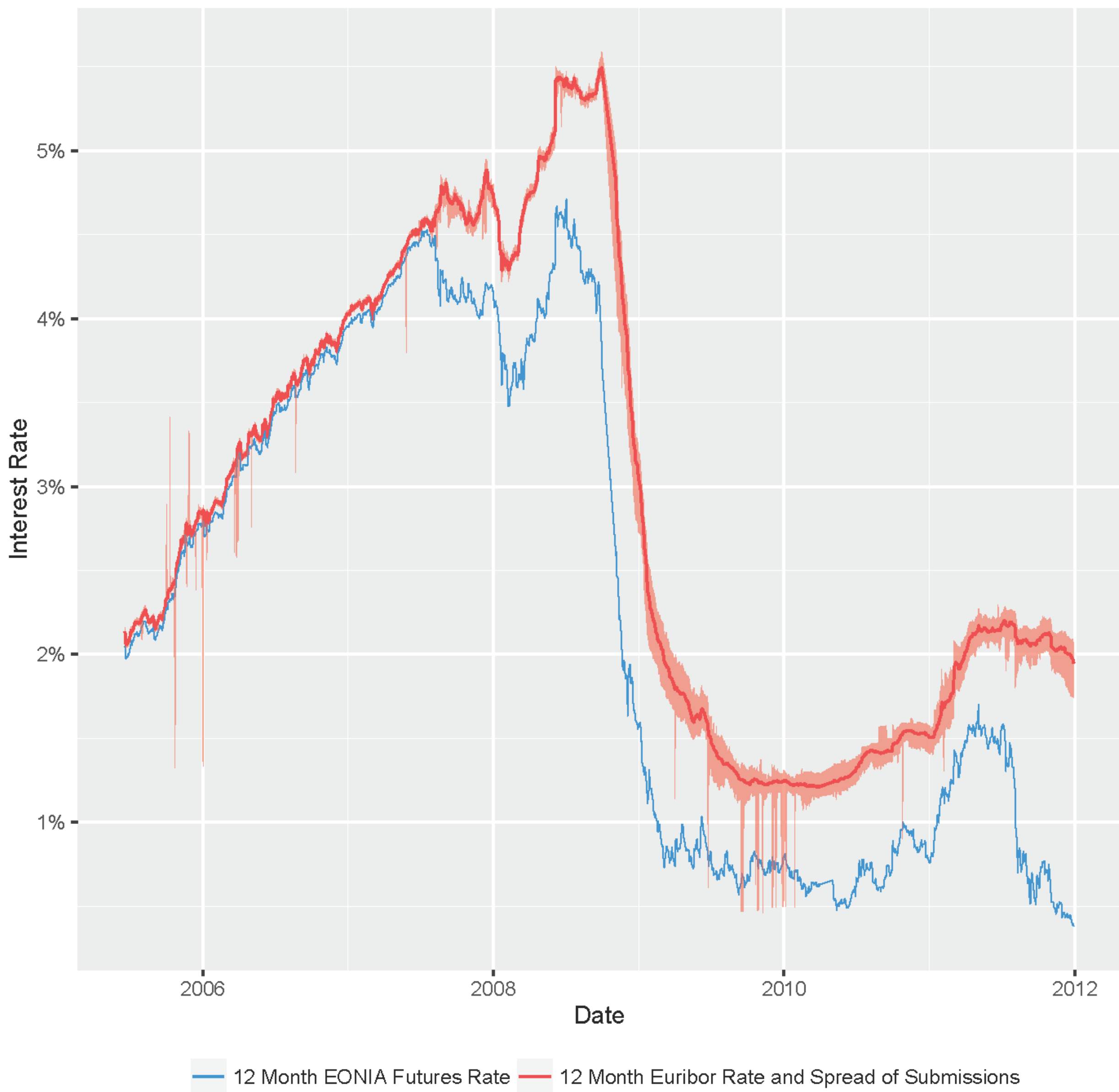

Figure 2: Comparison of the 12 month Euribor rate (the LIBOR equivalent for borrowing in Euros) and the 12 month EONIA futures rate, an instrument with the same maturity, but which pays the average of the overnight interest rate specified in most Euro-denominated CSAs over a 12-month time period. The light red region around the Euribor rate indicates the spread of submissions made by individual banks.

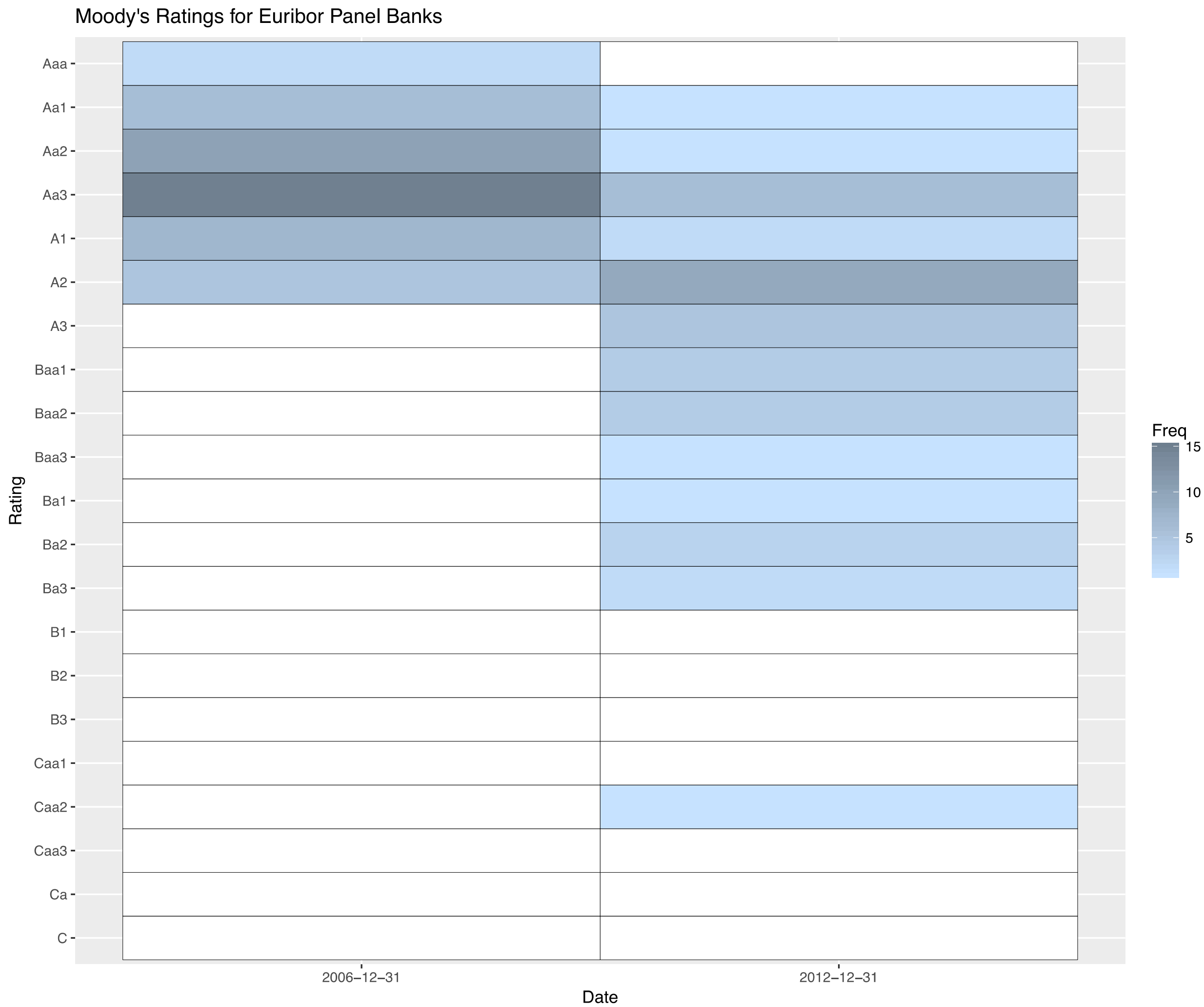

Figure 3: Moody's Credit Ratings for Euribor panel banks, before and after the 2008 financial crisis.